Zoosyst. Evol. 101 (4) 2025, 2055–2064 | DOI 10.3897/zse.101.167593

PENSOFT

für Naturkunde MUSEUM FÜR NATURKUNDE BERLIN

Description of new sand-dwelling *Rhynchothorax* species (Pycnogonida, Rhynchothoracidae) from Korean waters with note on novel morphological traits

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https://zoobank.org/FE55872D-977C-400D-ACB1-81C0172D12FB

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Academic editor: Danilo Harms ♦ **Received** 3 August 2025 ♦ **Accepted** 30 September 2025 ♦ **Published** 28 October 2025

Abstract

A new species belonging to the genus *Rhynchothorax* was discovered in a subtidal sandy patch off the eastern coast of Jejudo Island, Republic of Korea. The new species, *Rhynchothorax arenigenus* **sp. nov.**, is morphologically close to *R. nopperabo*, *R. philopsammum*, and *R. vallatus*, but can be distinguished by a combination of morphological characters: an ectal tubercle at the lateral extension of cephalic segment, the lateral process intervals, the arrangement of spines and tubercles on the lateral processes, the oviger spine formula, leg tuberculation, and the relative length of auxiliary claws. We highlight three morphological traits in the present species: a pair of ventral furrows on the proboscis, variable lateral process intervals, and the structure of oviger terminal claw. Notably, the ventral furrows are described here for the first time within the genus and may have been overlooked in other *Rhynchothorax* species. Additionally, partial sequences of mitochondrial cytochrome c oxidase subunit I (*cox1*) are provided to support species delimitation and to facilitate future phylogenetic research.

Key Words

Cox1, furrow, *Rhynchothorax*, sexual dimorphism, taxonomy, terminal claw

Introduction

The genus *Rhynchothorax* Costa, 1861 is a small group within pycnogonid genera, comprising 23 known species in the world (Müller 1993; Matsushita and Kakui 2024; Bamber et al. 2025). This genus is characterized by unique morphological traits that distinguish it from other pycnogonid genera as follows: 1) tiny trunk length typically less than 2 mm, 2) integument usually papillose or granulated, 3) palps bearing at least one distinct tubercle, 4) absence of chelifores, and 5) presence of ovigers in both sexes with a terminal claw (Arnaud and Krapp 1990; Child 1995; Matsushita and Kakui 2024). Species of this genus are known to be psammophilous, occurring in coarse substrates such as coral rubble, sand, or gravel, and inhabiting a wide bathymetric range from intertidal zones to depths exceeding 1,100 m (Hedgpeth 1951; Stock 1989; Child 1990; Staples 2019; Matsushita and Kakui 2024).

During a field survey at the eastern coast of Jejudo Island, a new species of *Rhynchothorax* was discovered in a sandy patch nestled between underwater cliffs and rocks. This species is distinguished from its congeners by a combination of morphological characters, including an ectal tubercle on the lateral extension of the cephalic segment, the intervals between the lateral processes, the presence and arrangement of spines and tubercles on the lateral processes, the oviger spine formula, leg tuberculation, and the relative length of auxiliary claws.

In this study, we describe a new *Rhynchothorax* species and discuss a detailed examination of three notable traits: the ventral furrows of the proboscis, the intervals between lateral processes, the structure of oviger terminal claw.

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Additionally, we provide partial sequences of mitochondrial cytochrome c oxidase subunit I (*cox1*) to support species delimitation and to facilitate future phylogenetic research.

Materials and methods

Sandy sediments were collected from a depth of 26.7 m by SCUBA diving around Sunrise Peak, Jejudo Island, Republic of Korea (Fig. 1). The sediments were rinsed with freshwater and sieved using a 1 mm mesh sieve, after which specimens were sorted and subsequently fixed and preserved in 95% ethanol. Specimens were then stained with lignin pink, and morphological characters were observed using a light microscope (Nikon Eclipse 80i, Japan) and a scanning electron microscope (SEM; JEOL JSM-6390LV, Japan). Images were taken with a microscope camera (Koptic HK-XCAM2160A, Republic of Korea) and focus stacking was performed using Helicon Focus software (Helicon Focus, Ukraine). SEM image resolution was enhanced with Real-ESRGAN (Wang et al. 2021). Digital line drawings followed the method of Coleman (2009). Measurements were conducted following Fry and Hedgpeth (1969) and Takahashi et al. (2007). Trunk length was measured from the anterior margin of the cephalic segment to the tip of the fourth lateral processes, and trunk width was measured across the second lateral processes. Segment lengths were measured between the midpoints of terminal surfaces; if a segment had a pointed end, it was measured from the midpoint of the proximal surface to the distal point. Trunk length and width were measured in dorsal view, while the proboscis, abdomen, and legs were measured in lateral view.

Total genomic DNA was extracted from whole-body specimens using the QIAamp DNA Micro Kit (QIAGEN, Germany) following the manufacturer's protocol. Partial sequences of mitochondrial cytochrome c oxidase subunit I (*cox1*) were amplified via polymerase chain reactions (PCR) using the primer set LCO1490 / HCO2198 (Folmer et al. 1994). Each 50 µL PCR mixture contained 0.25 µL of TaKaRa Ex Taq (TaKaRa Bio, Japan), 5 µL of 10X Ex Taq buffer, 4 µL of dNTP, 1 µL of each primer, 1 µL of template gDNA, and 37.75 µL of distilled water. The amplification conditions were as follows: initial denaturation at 94 °C for 4 min; 40 cycles of denaturation at 94 °C for 30 s, annealing at 42 °C for 30s and extension at 72 °C for 1 min; followed by a final extension at 72 °C for 10 min. Amplified fragments were sequenced using an ABI PRISM 3700 DNA analyzer (Applied Biosystems, USA), and sequences were edited and assembled with Geneious Prime v.2023.0.4 (Biomatters, New Zealand). Homologous gene sequences of mtDNA *cox1* were retrieved from GenBank (Table 1) and a total of 610 bp was aligned using MAFFT (Katoh et al. 2002). Genetic distances were calculated using the uncorrected *p*-distance method in MEGA X (Collins et al. 2012; Srivathsan and Meier 2012; Stecher et al. 2020).

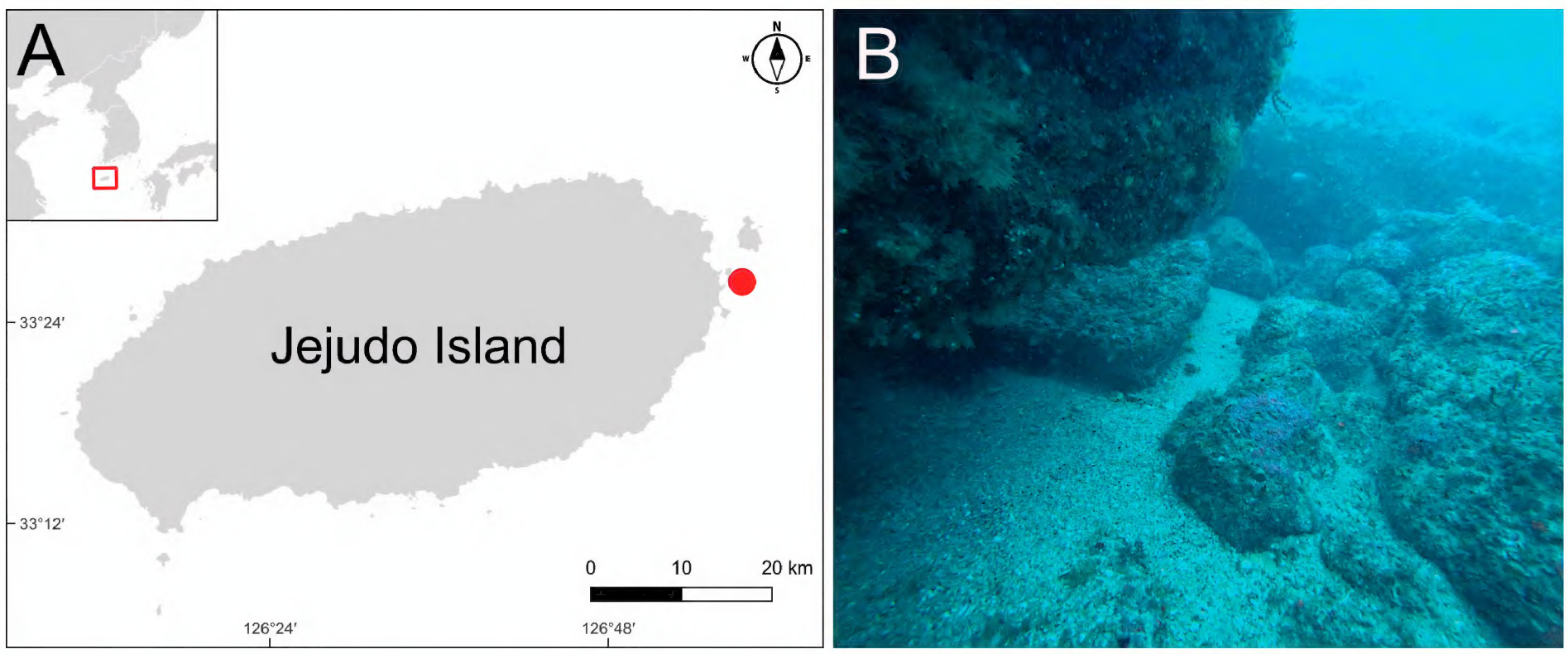

Figure 1. Distribution and natural habitat of *Rhynchothorax arenigenus* sp. nov. **A.** Distribution in Jejudo Island (type locality); **B.** Natural habitat, sandy patch nestled between underwater cliffs and rocks, photograph captured using a GoPro camera by D. Lee.

Table 1. Nucleotide sequences of mtDNA *cox1* gene used for calculating genetic distances among *Rhynchothorax* species.

Species	Specimen No.	NCBI No.	Reference
R. arenigenus sp. nov.	NIBRIV0000927837	PX048025	This study
R. arenigenus sp. nov.	NIBRIV0000927835	PX048026	This study
R. arenigenus sp. nov.	HNIBRIV23076	PX048027	This study
R. crenatus	MNHN-IU-2016-852	MK411165	Sabroux et al. 2019
R. sidereus	MNHN-IU-2016-817	MK411138	Sabroux et al. 2019

Specimens were deposited in the National Institute of Biological Resources (NIBR), Incheon, and the Honam National Institute of Biological Resources (HNIBR), Mokpo, Republic of Korea. Comparative materials were examined from the Museum Support Center of Smithsonian National Museum of Natural History (USNM) and the Senckenberg Research Institute and Natural History Museum (SMF).

Results

Systematic account

Order Pantopoda Gerstäcker, 1863
Family Rhynchothoracidae Thompson, 1909
Genus *Rhynchothorax* Costa, 1861

***Rhynchothorax arenigenus* sp. nov.**
https://zoobank.org/16EF930B-7E40-487B-B179-20B7A14330FB

Material examined. ***Holotype.*** Republic of Korea • 1 ♂; subtidal zone off Sunrise Peak (Seongsan Ilchulbong), Seogwipo-si, Jeju-do; 33°27'14.2"N, 126°56'59.2"E; depth 26.7 m; 24 Oct. 2023; DM Lee leg.; sand sieving, 24 °C, SCUBA diving; NIBRIV0000927835. ***Paratype.*** Republic of Korea • 1 ♀; same data for holotype; NIBRIV0000912890 • 1 ♀; same data as for holotype; NIBRIV0000927836 • 1 ♂; same data as for holotype; NIBRIV0000927837 • 1 ♀; same data for holotype; HNIBRIV23076.

Comparative material. *Rhynchothorax philopsammum* Hedgpeth, 1951. ***Holotype.*** USA • 1 ♀; California, Tomales Bay Bluff, Marin County; 27 Jan. 1949; R. J. Menzies leg.; USNM91245. ***Paratype.*** USA • 2 ♀♀; same data for holotype; USNM91246. ***Other material.*** French Polynesia • 5 ♀♀; Reef at Vaitape, Bora Bora, Society Islands; depth 0.5–1 m; 27 Feb.–06 Mar. 1988; SMF1080. Colombia • 2 ♂♂, 1 juv.; Magdalena, Punta de Betin, Santa Marta; depth 0–0.5 m; 31 Dec. 1985; under stones and sandy bottom; SMF1538.

Description. Male. Trunk fully segmented, tapering posteriorly, finely granulated, without dorsal tubercles (Figs 2, 3). Cephalic segment with pair of projections at anterodorsal margin, pair of low tubercles present at middle of neck, cylindrical lateral extension bearing small ectal tubercle (Figs 2A, 3A, B). Lateral processes shorter than diameter, separated by half of diameter; small dorsal seta present on center of first lateral process and on dorsodistal margin of other lateral processes (Fig. 2A, B). First lateral processes with two posterior tubercles; upper tubercle small, present at proximal; lower one large, present at distal. Second lateral processes having smaller anterior tubercle and two similar posterior tubercles. Third lateral processes bearing anterior tubercle and smaller posterior tubercle. Fourth lateral processes with small anterior tubercle. Ocular tubercle absent.

Proboscis spindle-shaped, having low dorsal protuberance at 2/3 from base, with three pairs of dorsolateral swellings, bearing pair of furrows on ventral surface (Figs 2A, B, 3A, 4C); mouth triradiate.

Abdomen cylindrical, tapering distally, directing horizontally, with nodulous dorsal surface, not reaching distal margin of second coxa (Fig. 2A, B).

Chelifores absent.

Palps five-articled, granular (Fig. 2C). First article very short. Second article cylindrical, longest, five times as long as diameter, with seta on dorsomedian and dorsodistal margin. Third article cylindrical, 1.5 times length of diameter, without seta. Fourth article distally widened, 3.7 times length of proximal diameter, bearing large dorsal tubercle at 2/3 from base, with setae on dorsal, ventral and distal surface; dorsal tubercle 1.5 times as high as proximal diameter of fourth article, armed with three setae. Fifth article bulged proximally on inner side and dorsally, armed with many setae.

Ovigers 10-articled, granular (Fig. 2D). First article short, attached to pectoralis major-like basement (Fig. 4C). Second article cylindrical. Third article swollen at inner surface. Fourth article tapering at proximal, longest, with setae on outer and distal surface. Fifth article curved, with short setae on outer surface. Sixth article cylindrical, second-longest, with short setae on outer-distal surface. Seventh article distally widened, as long as third article, bearing four tufts of spines on inner- and latero-distal surface (Fig. 3C). Eighth article bearing four tufts of spines on inner and lateral surface. Ninth article bearing three tufts of spines on inner surface, with seta on lateral surface. Terminal article curved, bearing two tufts of spines on lateral and inner surface, having simple spine and serrated lamina on distal margin, with outer seta. Terminal claw curved, with flattened inner surface (Fig. 3D).

Third leg granular, sparsely setose (Fig. 2E). First coxa as wide as lateral processes, with anterodistal tubercle on first legs; anterodistal tubercle and posteroproximal nodulous ridge on second legs; anterior and posterior tubercles on third legs; small anterior and posterior tubercles on distal margin of fourth legs (Figs 2A, B, 4D). Second coxa elongated, longest among three coxae, with large curved tubercle on posterior surface. Third coxa slightly longer than first coxa, with several setae on ventral surface. Femur longest, with long seta on dorsodistal margin. First tibia as long as second tibia, with long seta on dorsodistal margin. Second tibia cylindrical, with long setae on dorso- and ventro-distal margin; dorsodistal seta longer than that of femur and first tibia. Tarsus short, approximately 1/6 length of propodus, with long seta on ventral surface. Propodus slightly curved, as long as tibiae, with several setae on dorsal surface, bearing six sole setae, without heel spine. Claw curved, 1/3 length of propodus. Auxiliary claws thin, 0.7–0.8 length of claw. Gonopores present on ventral surface of second coxa on fourth legs (Fig. 3E).

Measurements (mm). Holotype (NIBRIV0000927835): Trunk length, 0.76; trunk width, 0.40; proboscis, 0.43; abdomen, 0.16. Paratype (NIBRIV0000927837): Third leg, first coxa, 0.07; second coxa, 0.12; third coxa, 0.09; femur, 0.20; first tibia, 0.18; second tibia, 0.18; tarsus, 0.03; propodus, 0.17; claw, 0.05; auxiliary claw, 0.04.

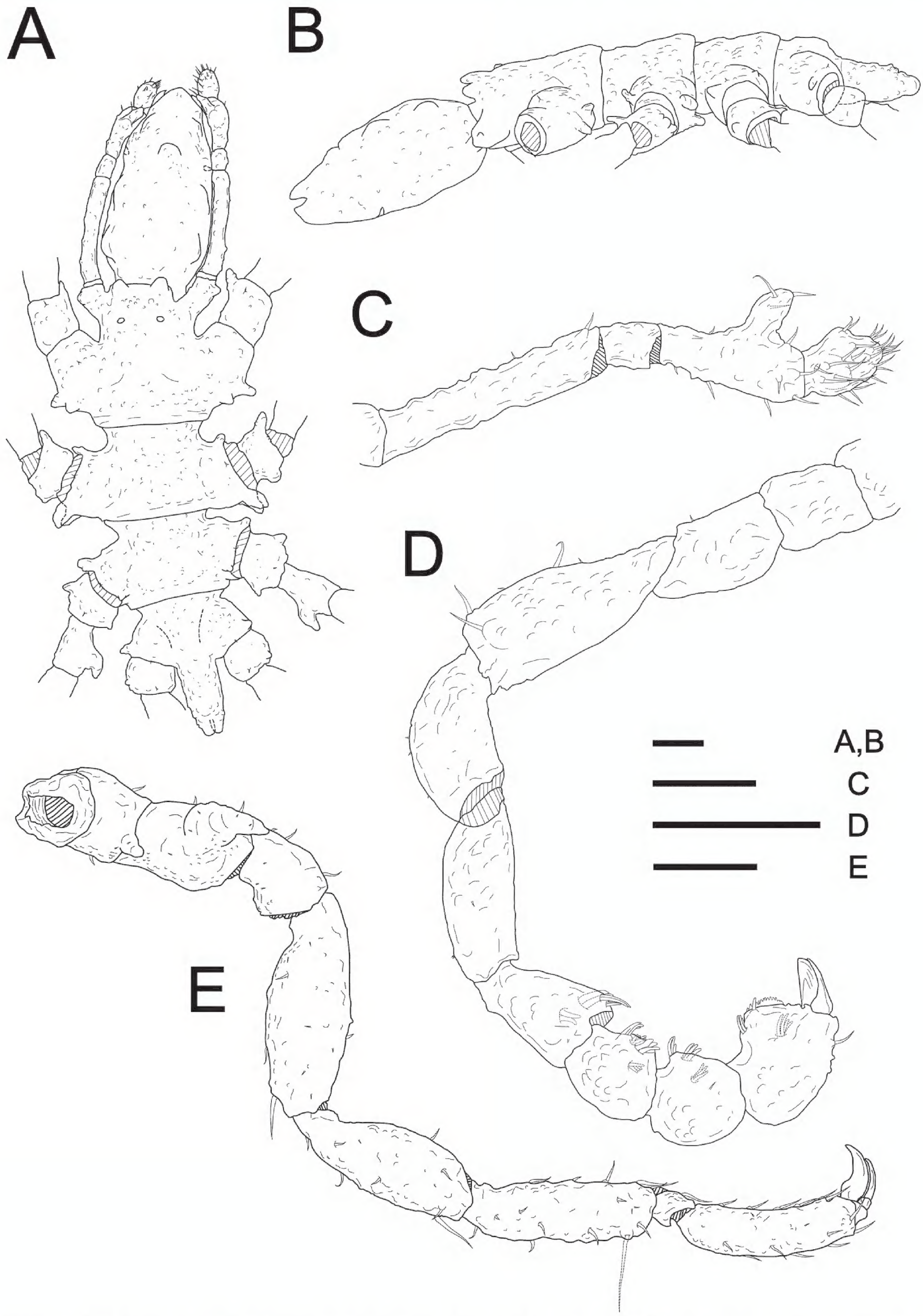

Figure 2. Morphology of *Rhynchothorax arenigenus* sp. nov. **A, B.** Holotype, male, NIBRIV0000927835; **C–E.** Paratype, male, NIBRIV0000927837; **A.** Trunk, dorsal view; **B.** Trunk, lateral view; **C.** Left palp; **D.** Left oviger; **E.** Third leg. Scale bars: 100 μm (**A–E**).

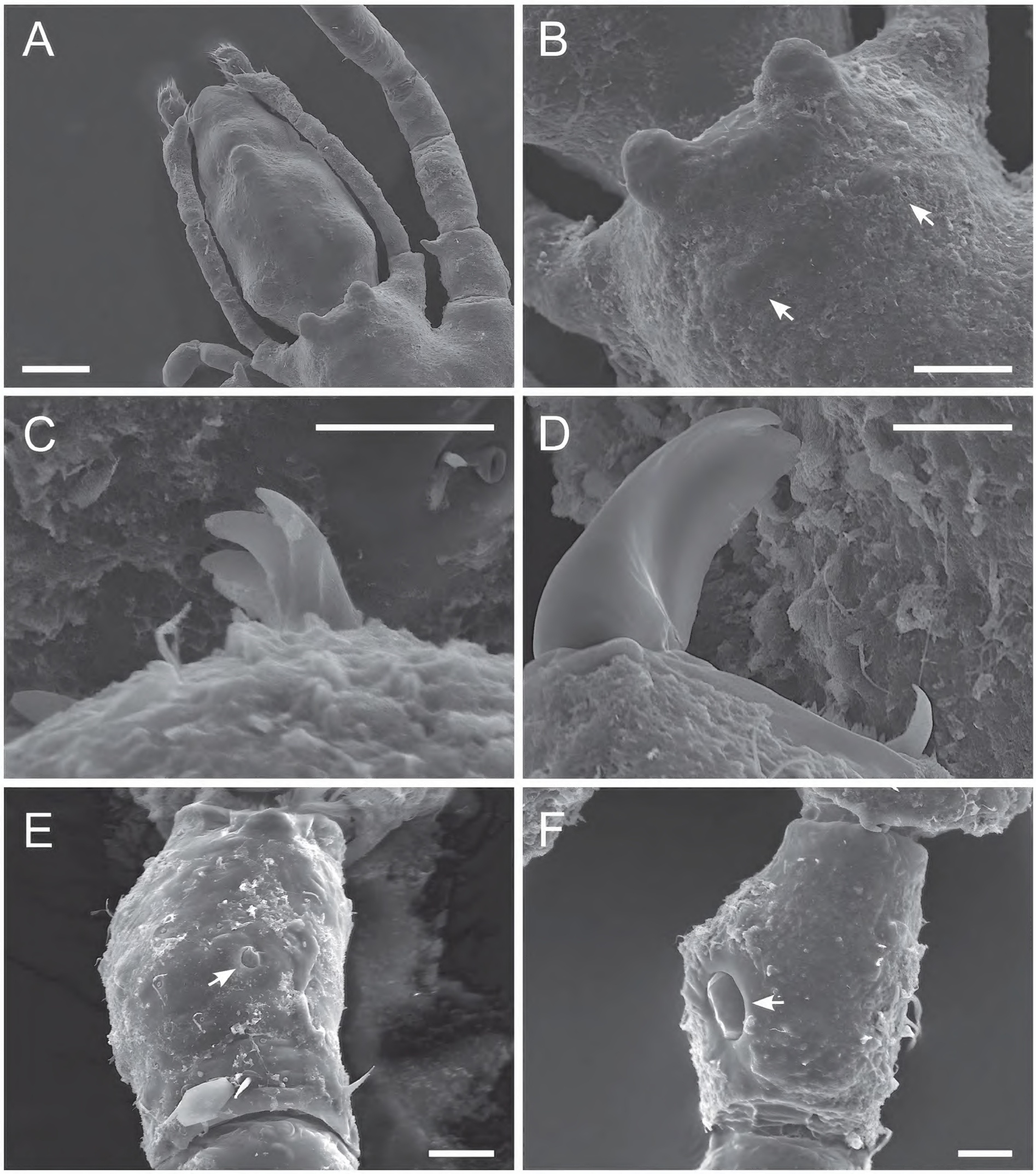

Figure 3. SEM images of *Rhynchothorax arenigenus* sp. nov. **A, B, E.** Male, NIBRIV0000927837; **C, D, F.** Female, HNIBRIV23076; **A.** Proboscis, dorsal view; **B.** A pair of projections at cephalic segment, arrows indicating a pair of low tubercles; **C.** A tuft of spines on strigilis; **D.** Terminal claw of oviger; **E.** Male gonopore, indicated by arrow; **F.** Female gonopore, indicated by arrow. Scale bars: 100 μm (**A**); 50 μm (**B, C**); 10 μm (**D**); 20 μm (**E, F**).

Etymology. The species name *arenigenus* is derived from the Latin "*arena* (sand) + -*genus* (meaning 'arising from' or 'born off')", referring to its natural habitat on sandy bottoms. The Korean names for the family, genus, and species are all pronounced "moraebadageomi", emphasizing the association with sandy environments.

Distribution. This species is only known from the type locality, Jejudo Island, Republic of Korea.

Remarks. *Rhynchothorax arenigenus* sp. nov. closely resembles *R. nopperabo* Matsushita & Kakui, 2024, *R. philopsammum* Hedgpeth, 1951, and *R. vallatus* Child, 1990 in lacking both ocular tubercle and dorsal tubercles on the trunk and proboscis. However, it can be distinguished from *R. nopperabo* by the presence of a small seta on each lateral process, two posterior tubercles on the first lateral processes, lateral process intervals about half the

diameter, and a small tubercle on both the anterior and posterior margin of the first coxa on the fourth legs, whereas in *R. nopperabo*, no seta is present on the lateral processes, only a posterior tubercle is present on the first lateral processes, the intervals are narrower, and the first coxa of the fourth legs has only a small posterior tubercle (or none).

Although *R. nopperabo* was originally described as lacking an ectal tubercle on the lateral extension of the cephalic segment and bearing only an anterodistal tubercle on the first coxa of the second legs and a posterior tubercle on that of the third legs (Matsushita and Kakui 2024), Dr. Keiichi Kakui kindly re-examined the type specimens of *R. nopperabo* deposited in the Invertebrate Collection of the Hokkaido University Museum and confirmed the presence of intraspecific variations (personal communication, see Table 2).

Compared to *R. philopsammum*, the ectal tubercle on the cephalic segment of the present species is smaller and less conspicuous, and the lateral process intervals are wider (Fig. 5). The fifth segment of the palp is dorsally bulged but does not reach the height of the dorsal tubercle on the fourth segment, while in *R. philopsammum*, the fifth segment is strongly curved, reaching the dorsal tubercle on the fourth segment. *Rhynchothorax arenigenus* sp. nov. also differs from *R. vallatus* in several traits: it has a shorter fifth palp segment, tufts of oviger spines with a formula of 4-4-3, a posteroproximal nodulous ridge on the first coxa of the second legs, distinct anterior and posterior tubercles on the first coxa of the third legs, and relatively longer auxiliary claws. In *R. vallatus*, by contrast, the fifth palp segment is more curved and reaches the height of the dorsal tubercle on the fourth segment, the strigilis bears simple spines with a formula of 2-1-1, posterior swellings or tubercles are absent on the first coxa of the second and third legs, and the auxiliary claws are shorter.

The present species exhibits sexual dimorphism in external morphology (Fig. 4A, B). Female specimens display similar or slightly larger trunk lengths compared to males (females NIBRIV0000912890, NIBRIV0000927836, HNIBRIV23076: 0.83 mm, 0.86 mm, and 0.88 mm, respectively; males NIBRIV0000927835 and NIBRIV0000927837: 0.76 mm and 0.83 mm, respectively). Tubercles or projections, such as those on the lateral extension of the cephalic segment, the

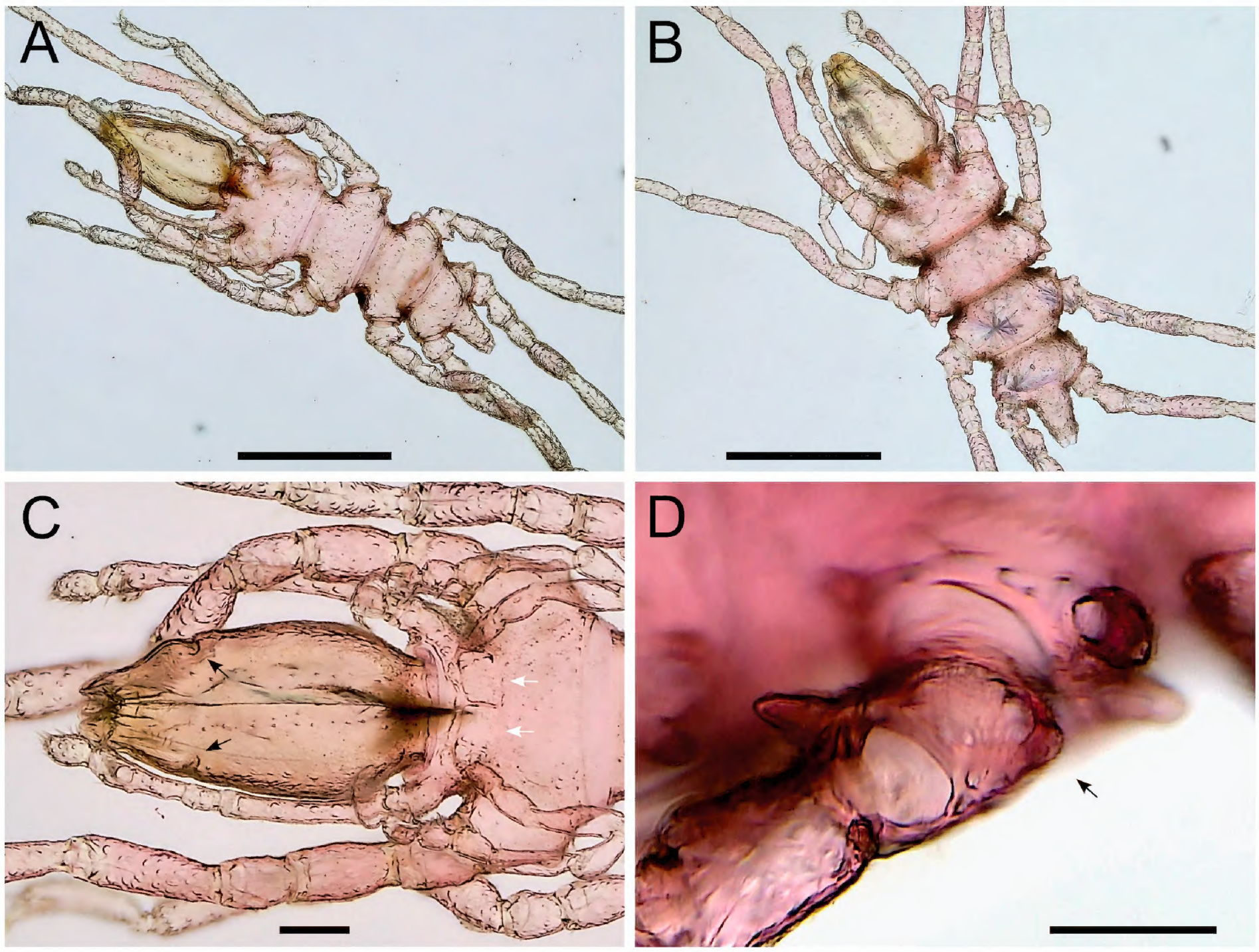

Figure 4. Images of *Rhynchothorax arenigenus* sp. nov. **A, C.** NIBRIV0000927836; **B.** HNIBRIV23076; **D.** NIBRIV0000927835; **A.** Female specimen, dorsal view; **B.** Female specimen, dorsal view; **C.** Anterior body of specimen, black arrows indicating furrows, white arrows indicating pectoralis major-like basement, ventral view; **D.** Posteroproximal nodulous ridge on second leg, indicated by arrow. Scale bars: 500 μm (**A, B**); 200 μm (**C, D**).

Table 2. Re-examination of morphological traits in type specimens of *Rhynchothorax nopperabo*.

Character	Holotype ICHUM8636	Paratype ICHUM8637	Paratype ICHUM8638	Paratype ICHUM8639
Ectal tubercle on lateral extension of cephalic segment	Absent	Present	Absent	Present
Small seta on lateral processes	Absent	Absent	Absent	Absent
No. of posterior tubercles on first lateral processes	1	1	1	1
Tubercles on first coxa of second legs	An anterior tubercle + nodulous posterior ridge	–	An anterior tubercle + nodulous posterior ridge	An anterior tubercle + nodulous posterior ridge
Tubercles on first coxa of third legs	A posterior tubercle	–	An anterior + a posterior tubercles	An anterior + a posterior tubercles
Tubercles on first coxa of fourth legs	Absent	–	A small posterior tubercle	Absent
Nodulous swelling on posterior surface of second coxa of third legs	Absent	Absent	Present	Present

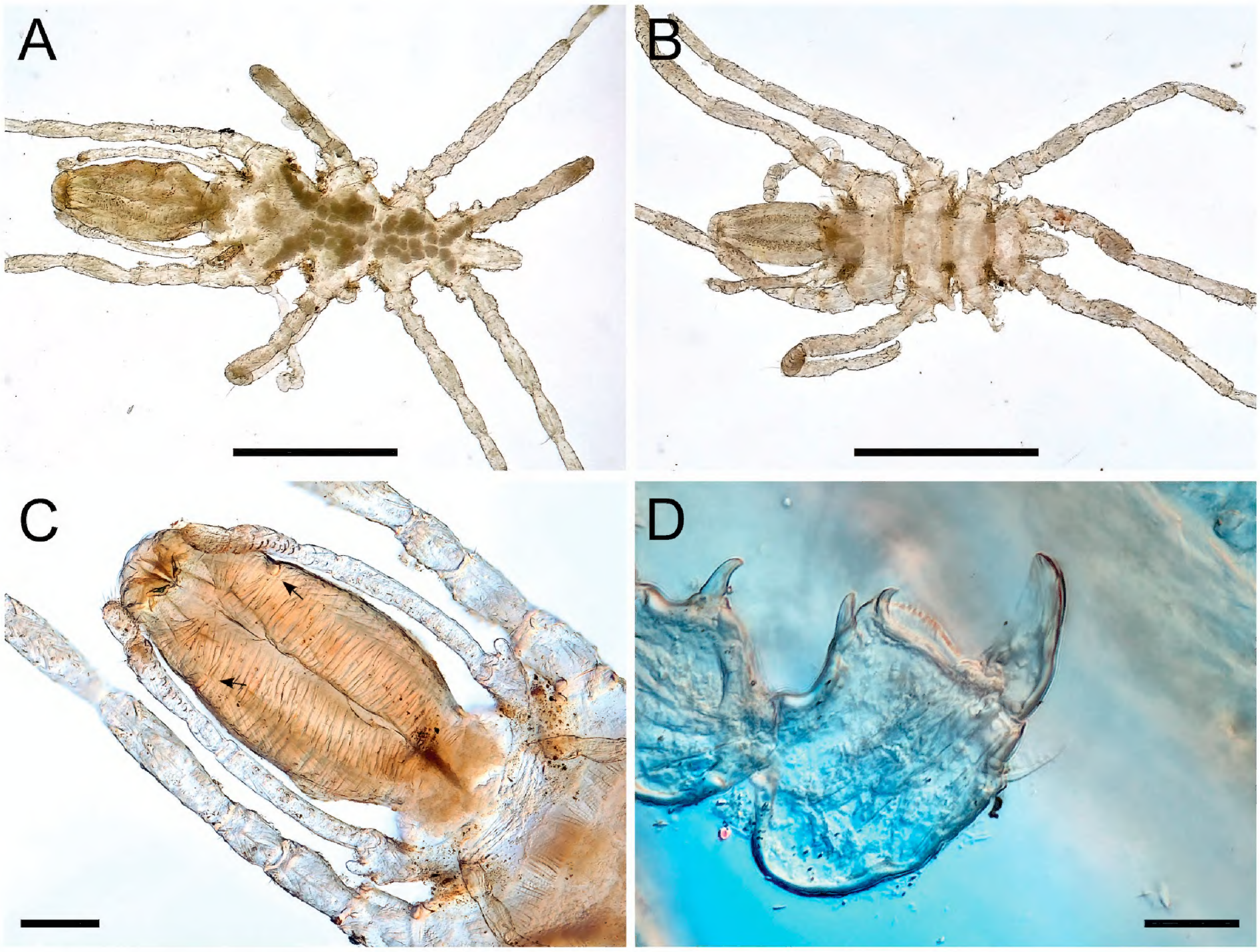

Figure 5. *Rhynchothorax philopsammum* **A, C.** Female, SMF 1080; **B, D.** Male, SMF 1538; **A.** Trunk, dorsal view; **B.** Trunk, dorsal view; **C.** Proboscis, arrows indicating furrows, ventral view; **D.** Terminal segment of oviger. Scale bars: 500 µm (**A, B**); 100 µm (**C**); 20 µm (**D**).

posterior surface of the first lateral processes, the first and second coxa of the third legs, are less prominent in females. Female gonopores are large and located on the inner surface of the second coxa of the fourth legs, whereas male gonopores are small and situated ventrally on the same coxa (Fig. 3F).

Mitochondrial *cox1* sequence analysis revealed very low intraspecific genetic distances (0–0.17%) between male and female specimens, whereas interspecific distances range from 24.45% (between *R. arenigenus* sp. nov. and *R. sidereus*) to 31.07% (between *R. crenatus* and *R. sidereus*) (Table 3). Considering that male and female

Table 3. uncorrected *p*-distances of mtDNA *cox1* gene among *Rhynchothorax* species.

	***R. arenigenus* (NIBRIV0000927837)**	***R. arenigenus* (NIBRIV0000927835)**	***R. arenigenus* (HNIBRIV23076)**	***R. crenatus***
R. arenigenus (NIBRIV0000927835)	0.17%			
R. arenigenus (HNIBRIV23076)	0.17%	0%		
R. crenatus	24.96%	24.96%	24.96%	
R. sidereus	26.45%	26.45%	26.46%	31.07%

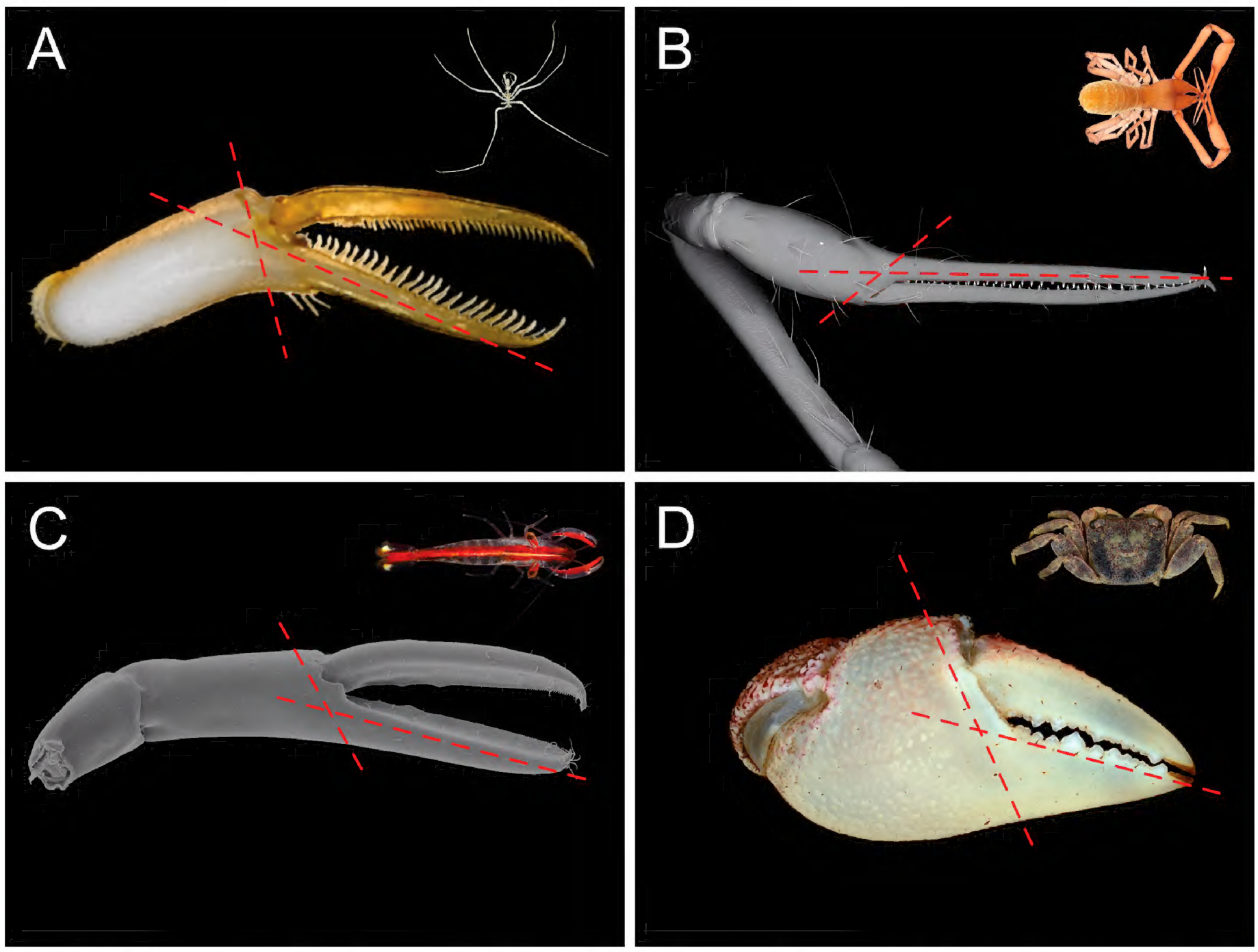

Figure 6. Chelate appendages in arthropods, with dashed lines indicating angles between gripping surface of immovable finger and proximal articulation of movable finger. **A.** Chelifore of pycnogonid, *Nymphon japonicum* Ortmann, 1891; **B.** Pedipalp of pseudoscorpion, *Spelaeochthonius geumgulensis* Jeong & Harms, 2025; **C.** Second cheliped of caridean shrimp, *Cristimenes brucei* Park, De Grave & Kim, 2019; **D.** Cheliped of crab, *Pachygrapsus crassipes* Randall, 1840. Specimens are from personal collections of Damin Lee (**A**); Kyung-Hoon Jeong (**B**); Jin-Ho Park (**C**); Bomi Kim (**D**). Photographs provided by Damin Lee (**A, D**); Kyung-Hoon Jeong (**B**); Jin-Ho Park (**C**).

specimens were collected from the same locality, that they share key diagnostic morphological characters of the new species, and that they exhibit very low genetic divergence, the morphological differences mentioned above are interpreted as sexual dimorphism.

Discussion

Our findings confirm that *R. arenigenus* sp. nov. represents a distinct species within the genus *Rhynchothorax*. Through detailed examinations, we recognized three novel morphological traits: (1) a pair of ventral furrows on the proboscis, (2) variable lateral process intervals, and (3) the structure of oviger terminal claw.

The proboscis in the genus *Rhynchothorax* consists of a dorsal and two ventrolateral antimeres, with the dorsal lip being much smaller than the ventrolateral ones (Fry 1965). Given that the lip muscles (referred to as "LpM") are only located in the ventrolateral antimeres and that the lip-opening musculature is relatively underdeveloped, this configuration appears unsuitable for wide mouth opening (Fry 1965). Under these circumstances, the presence of ventral furrows on the proboscis is presumed to facilitate the expansion of the ventrolateral lips by providing additional space (Figs 4C, 5C).

Although *R. australis* Hodgson, 1907 is known to prefer hydroids to bryozoans and poriferans as food, knowledge of the feeding biology of this genus remains limited (Fry 1965; Dietz et al. 2018). Meiofaunal surveys conducted in bottom sediments near the type locality, Sunrise Peak, revealed abundant Nematoda and Harpaticoida, followed by nauplius and Polychaeta (Pavlyuk and Trebukhova 2011; Kang and Kim 2020). Considering the small body size of *R. arenigenus* sp. nov. and the meiobenthos community, these invertebrates are likely to be food sources (Arnaud and Bamber 1988; Soler-Membrives et al. 2013; Dietz et al. 2018). The ventral furrows may thus play a functional role in enabling the mouth to open more widely to ingest such minute prey from the sediments.

Second, in pycnogonid taxonomy, the lateral process intervals have traditionally been used as one of diagnostic key characters. Since trunk segments are connected to each other via articulations, allowing for flexibility (Arnaud and Bamber 1988), the contraction and expansion of these segments can cause variation in the lateral process intervals (Fig. 4A, B). Therefore, this character should be interpreted with caution in *Rhynchothorax*, and ideally, observations should be made across a wide range of specimens.

Finally, the oviger terminal claw and lamina have been described as forming a subchelate structure in several studies (Clark 1976; Child 1979, 1988; Stock 1989), but a flattened inner surface of the terminal claw has been noted only in *R. alcicornis* Krapp, 1973 (as a "flattened claw"), *R. coralensis* Staples, 2019 ("broad cutting edge"), and *R. sidereus* Sabroux in Sabroux, Hassanin, Corbari, 2022 ("inner surface flattened"). In chelifores of pycnogonids or other chelate appendages of arthropods, effective clamping is typically achieved when the gripping surface of the immovable finger forms an adequate angle with the proximal articulation of the movable finger, especially when the fingers are not strongly curved (Fig. 6). However, in specimens of both *R. arenigenus* sp. nov. and *R. philopsammum*, the lamina and the terminal claw articulation are nearly parallel, suggesting this structure is poorly suited for strong clamping (Figs 3D, 5D). Instead, this configuration may be adapted for egg grooming or cleaning functions via a flat-surface sweeping mechanism rather than typical chelate grasping.

Notably, the ventral furrows on the proboscis have not been previously reported in this genus, and the flattened inner surface of the oviger terminal claw has only been described in three other species. However, both traits were observed in the specimens of *R. philopsammum* (SMF 1080 and SMF1538) that we re-examined in the present study (Fig. 5). These traits may have been overlooked in previous studies. Our observations suggest that these traits may be more widespread within the blinded *philopsammum*-group or possibly throughout the genus, thereby highlighting the need for re-examination of other species within the genus *Rhynchothorax*.

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Funding

This research was supported by a grant from the National Institute of Biological Resources (NIBR), funded by the Ministry of Environment (MOE) of the Republic of Korea (NIBR202302103) and Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2021R1A6A3A01086386).

Author contributions

DL: sampling, conceptualization, analysis, writing (draft manuscript). JP: conceptualization, writing (review & editing). TP: supervision, validation, writing (review & editing).

Data availability

All of the specimens and sequence data (PX048025–27) that support these findings are deposited in NIBR (Incheon), HNIBR (Mokpo) and GenBank, respectively.

Acknowledgements

We are deeply grateful to Dr. Keiichi Kakui (Hokkaido University, Japan) for re-examining the type specimens of *R. nopperabo*. We also sincerely thank Dr. Jina Park (National Marine Biodiversity Institute of Korea, Republic of Korea), Dr. Yukyung Kim and Haelim Kil (Ewha Womans University, Republic of Korea), as well as SCUBA diving instructors Dr. Seungu La (Ocean Research, Republic of Korea) and Gwanyoung Song (PADI, Republic of Korea), for their valuable assistance during field surveys. We also appreciate Karen Reed (Smithsonian National Museum of Natural History, USA), Dr. Angelika Brandt and Kristin Arnold (Senckenberg Research Institute and Natural History Museum, Germany), and Bomi Kim (NIBR, Republic of Korea) for providing access to important specimens. We are further indebted to Dr. Romain Sabroux (Stazione Zoologica Anton Dohrn Napoli, Italy) for sharing valuable literatures and to Kyung-Hoon Jeong (Jeonbuk National University, Republic of Korea) for providing photographs of a pseudoscorpion, *Spelaeochthonius geumgulensis* Jeong & Harms, 2025.

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